THE

JOURNAL OF GEOLOGY

JULY–AUGUST, 1910

NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN[1]

PART II. FROM THE ST. PETER SANDSTONE UP

A. C. LANE
Tufts College, Mass.

INTRODUCTION

An apology is due for the long gap which has elapsed between the publication of Part I and Part II. This is due to the fact that I wished to have the benefit of the work of Professors A. W. Grabau and W. H. Sherzer without trespassing upon their rights. This I can now do[2] though we are not yet in accord as to interpretation. Perfect accord, however, cannot be expected. An advantage is that in the mean time Schuchert's[3] and other paleogeographic studies have appeared. This paper was written before Schuchert's and independently, so that the numerous confirmations of his maps are valuable checks, while discrepancies have not been subject to critical revision. Almost all the places referred to will be found underlined on a map in Vol. V of the *Mich. Geol. Survey*, and detailed references to the facts upon which the statements of this paper are based will be found in the report for 1908.

The second, or upper part of the Michigan rocks here described, including Ordovician and Carboniferous, has peculiar interest in many ways. In the first place it stands as the connecting field between the standard New York and the Mississippi Valley rocks.

[1] Part I appeared in XV, 680, of this *Journal*.

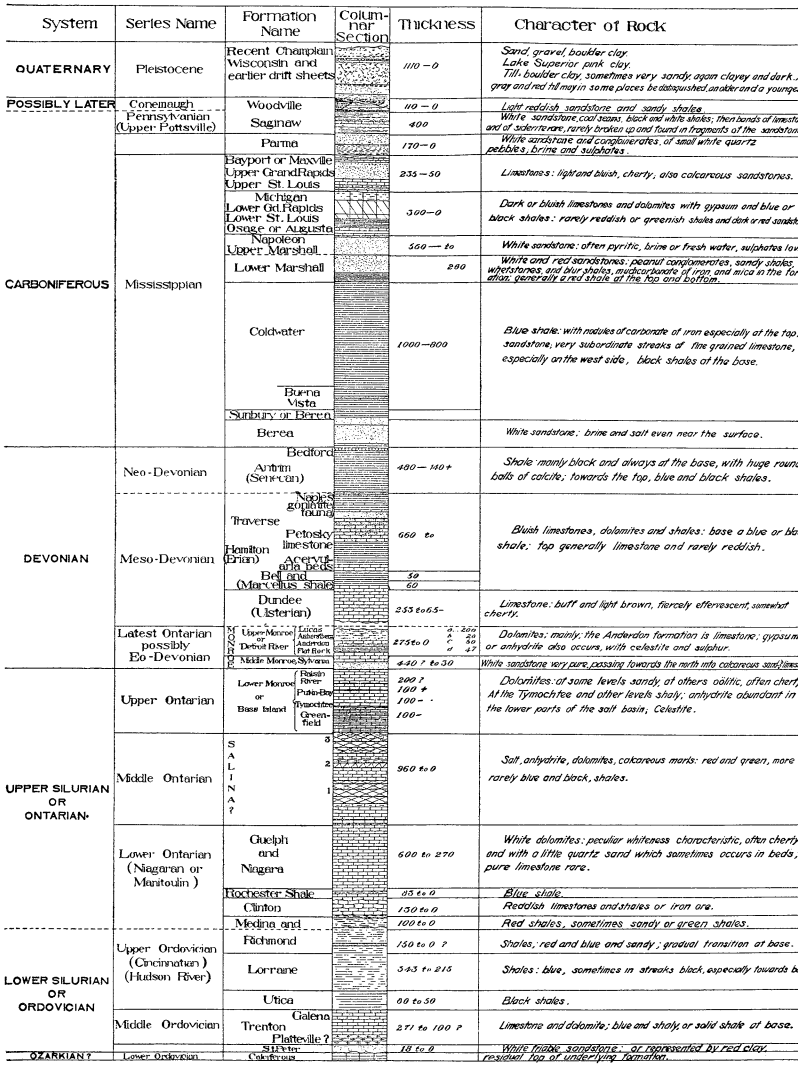
[2] See Grabau's papers in *Science*, No. 739 (1909), 356; *Bull. G.S.A.*, XVII, 567–636; XIX, 540–53.

[3] *Bull. G.S.A.*, XX (1910), 427–606.

In the second place it has not been much disturbed. It is too much to say not at all disturbed, for there is caught in the synclinal fold of Limestone Mountain on Keweenaw Point the Niagaran, so that we are led to infer that notable disturbance took place along the line of the Great Keweenaw fault after the Niagara. There are in the Lower Peninsula also signs of slight foldings at various times. But on the whole the strata lie in one vast little-disturbed *persistent* basin, Schuchert's Ontario Traverse Basin, in a gentle embayment of the great pre-Cambrian boss or shield which curves around them from Wisconsin on the west to Canada on the east. It is possible that at the center of this basin Paleozoic deposition was continuous, perhaps not always marine.

A notable feature is the general fineness of the sediments and absence of conglomerates. These latter are extremely rare. If one overlooks some perhaps autoclastic limestone calcirudites, occasional pebbles of quartz as big as peanuts and in the Marshall a few narrow thin bands of conglomerate containing very little but quartz, he may say there are none. The wide variety of crystalline and igneous rocks which lie only a short distance northeast to northwest are practically absent until, of course, we come to the glacial till, where they are abundant. These facts seem strong grounds for believing that during all the Paleozoic time this great area was neither glaciated nor violently disturbed and uplifted. We ought to have therefore in the Michigan section an ideal place, where the strata are well exposed, to study those universal advances and retreats of the shore-line which must have occurred as the ocean level was raised the world over by filling-in of sediments, or lowered by falling-in of blocks of the ocean floor. It is likely that we can recognize already the broad outlines of Huntington's steady and more unsteady periods as follows:

Relatively Steady	Relatively Unsteady
Jurassic and Cretaceous	Tertiary and Quaternary
Upper Mississippian	Permo-Carboniferous and Triassic (New Red)
Middle Devonian	Upper Devonian (Old Red)
Niagaran	Lower Devonian and Late Silurian
Trenton-Utica	Upper Ordovician Lorraine to Clinton
(Ozarkian ?) Calciferous ?	St. Peter sandstone minor
	Early Cambrian and Keweenawan
Animikie black slate	Palms and Goodrich
Kona dolomite and Grenville limestone	Possibly an oscillation below Keewatin



System	Series Name	Formation Name	Thickness	Character of Rock
QUATERNARY	Pleistocene	Recent Champlain Wisconsin and earlier drift sheets	1110 — 0	Sand, gravel, boulder clay. Lake Superior pink clay. Till, boulder clay, sometimes very sandy again clayey and dark. A gray and red till may in some places be distinguished, an older and a younger.
POSSIBLY LATER	Coremaugh	Woodville	110 — 0	Light reddish sandstone and sandy shales.
CARBONIFEROUS	Pennsylvanian (Upper Pottsville)	Saginaw	400	White sandstone, coal seams, black and white shales, thin bands of limestone and of siderite rare, rarely broken up and found in fragments of the sandstone.
		Parma	170—0	White sandstone and conglomerates, of small white quartz pebbles, brine and sulphates.
	Mississippian	Bayport or Maxville	235—50	Limestones: light and bluish, cherty, also calcareous sandstones.
		Upper Grand Rapids		
		Upper St. Louis		
		Michigan	300—0	Dark or bluish limestones and dolomites with gypsum and blue or black shales: rarely reddish or greenish shales and dark red sandstone.
		Lower Gt. Rapids		
		Lower St. Louis		
		Osage or Augusta		
		Napoleon	50 — to	White sandstone: often pyritic, brine or fresh water, sulphates low.
		Upper Marshall		
		Lower Marshall	290	White and red sandstones: peanut conglomerates, sandy shales; whetstones, and blue shales, radiocarbonate of iron and mica in the formation, generally a red shale at the top and bottom.
		Coldwater	1000—800	Blue shale: with nodules of carbonate of iron especially at the top; sandstone, very subordinate streaks of fine grained limestone, especially on the west side, black shales at the base.
		Burna Vista		
		Sunbury or Berea		
		Berea		White sandstone; brine and salt even near the surface.
DEVONIAN	Neo-Devonian	Bedford Antrim (Senecan)	480 — 140+	Shale: mainly black and always at the base, with huge round balls of calcite; towards the top, blue and black shales.
	Meso-Devonian	Traverse Nodosa goniatite young	660 to	Bluish limestones, dolomites and shales: base a blue or black shale; top generally limestone and rarely reddish.
		Hamilton (Erian) Petosky limestone		
		Acervularia beds		
		Bell and (Marcellus Shale	50 60	
		Dundee (Ulsterian)	235 to 65-	Limestone: buff and light brown, fiercely effervescent, somewhat cherty.
	Latest Ontarian possibly Eo-Devonian	Upper Monroe or Detroit River: Lucas, Amherstburg, Anderdon, Flat Rock	A 200 B 50 C 50 D 47 — 275 to 0	Dolomites: mainly; the Anderdon formation is limestone; gypsum or anhydrite also occurs, with celestite and sulphur.
		Middle Monroe, Sylvania	430 ? to 30	White sandstone very pure, passing towards the north into calcareous sand limestone
UPPER SILURIAN OR ONTARIAN	Upper Ontarian	Lower Monroe or Bass Island: Raisin River, Put-in-Bay, Tymochtee, Greenfield	200 ? 100 ± 100 — 100—	Dolomites: of some levels sandy, at others oölitic, often cherty. At the Tymochtee and other levels shaly; anhydrite abundant in the lower parts of the salt basin, Celestite.
	Middle Ontarian	SALINA ? 3 2 1	960 to 0	Salt, anhydrite, dolomites, calcareous marls: red and green, more rarely blue and black, shales.
	Lower Ontarian (Niagaran or Manitoulin)	Guelph and Niagara	600 to 270	White dolomites: peculiar whiteness characteristic, often cherty, and with a little quartz sand which sometimes occurs in beds; pure limestone rare.
		Rochester Shale	85 to 0	Blue shale.
		Clinton	150 to 0	Reddish limestones and shales or iron ore.
		Medina and	100 to 0	Red shales, sometimes sandy or green shales.
LOWER SILURIAN OR ORDOVICIAN	Upper Ordovician (Cincinnatian) (Hudson River)	Richmond	150 to 0 ?	Shales, red and blue and sandy; gradual transition at base.
		Lorraine	343 to 215	Shales: blue, sometimes in streaks black, especially towards base.
		Utica	60 to 50	Black shales.
	Middle Ordovician	Trenton Galena Platteville ?	271 to 100 ?	Limestone and dolomite; blue and shaly, or solid shale at base.
		St. Peter Calciferous	18 to 0	White friable sandstone: or represented by red clay residual top of underlying formation.
OZARKIAN ?	Lower Ordovician			

ORDOVICIAN

11. *St. Peter sandstone.*—There is no probability that these periods are of uniform length or intensity of oscillation. The unsteady period between the Trenton and Calciferous (Canadic-Ordovicic) appears to be much less important than the great period terminating in the Lake Superior overlap which in Michigan at least may include a good part of Ulrich's Ozarkian,[1] and perhaps earlier (the Keweenawan) during which Michigan was out of water and rent by tremendous volcanic outbursts.

In an emergence sandstone the sand itself, being rehandled along a rising coast, is more likely to be uniform in texture. Its connate water may be fresh at the margin. In many respects the St. Peter sandstone is a typical emergence sandstone as compared with the Lake Superior sandstone and that is one reason why I do not think it extends into the Lake Superior basin. As Schuchert's curve[2] indicates it does not mark so much emergence. My remarks in Part I that the viewpoint of one studying drillings is different from that of one studying outcrops in such a basin as Lower Michigan must not be forgotten. The gaps due to discordances and disconformities are liable to be much greater; the emergence sandstones less at the outcrop that at the center of the basin. Both the St. Peter and the Berea I take to be emergence sandstones in Michigan, and neither of them have been recognized as outcrops, though distinct in some drill records. The base of an emergence sandstone is probably a more definite datum plane than that of a submergence sandstone.

The greatest thickness of the St. Peter seems to be to the southwest. Just outside the state at Marinette, No. 2 well apparently gives 75 feet of it from 325–400 feet. But how rapidly it thins and how irregular it is, is shown by the fact that at Gladstone it was not distinctly recognized, and across the Bay de Noe perhaps represented only by a red clay shale, the weathered surface of the Calciferous dolomite. It seems to fill hollows in the eroded Calciferous quite as in Wisconsin. Farther east it is not known. The Pickford record is imperfect, and in the Neebish samples, if present, it is indistinguishable from the Lake Superior sandstone.

[1] Schuchert, *Science*, XXIX (1909), 630; *Bull. G.S.A.*, XX, No. 20.

[2] *Op. cit.*, Pl. 101.

12. *Trenton limestone.*—Under this head have been grouped, as appears from Foster & Whitney's map, and the text by them (p. 140, Hall and others) equivalents to the Chazy, Birdseye, Black River, and Trenton in its narrower sense of New York. We are thus including all the Mohawkian and the Chazy, the lower half of Schuchert's Ordovicic. Grabau would include all up to the Black River in his Chazyan or Middle Ordovician, and would also combine the Trenton with the overlying Utica. In a general way it is what Bigsby referred to (1823, pp. 195–96) as the "limestone of St. Joseph." He refers to its typical exposures on St. Joseph Island and figures characteristic fauna. He also gives an excellent lithological description, mentioning the characteristic "Birdseye," or as he calls it "knotty," texture of some parts.

Pleading that neither at top nor bottom do our dividing lines exactly agree in time with the New York column, Grabau would suggest a local name like Escanaba. But it is entirely unlikely that the dividing lines are exactly the same at the two ends of the Upper Peninsula—that is, on the Escanaba and St. Mary's rivers where alone it has been, or can be, studied. Still less likely is it that where it has been struck in deep wells at the other end of the state, it is the same. Yet all over this vast area the line of change to black shale (Utica) from limestone or dolomite is well marked and of practical importance. It probably represents not very far from the same time. In fact, why should not a change in sedimentation at this point be due to diastrophism involving an instantaneous or simultaneous change over a wide area, a general retreat of ocean due to a large drop in its bottom somewhere, both shallowing the sea and exposing the land to renewed erosion and so muddying the waters?

For subdivisions we may use the Green Bay wells:

Galena limestone, crystalline, granular	83
Limestone, fossiliferous 55 ft., white 8 ft., dark 9 ft.	72
Alternating blue and brown, crystalline, granular. With the dark base compare the Wisconsin oil rock	225
Sandy limestones, "quartz" 6 ft., limestone 44 ft., quartz 1 ft., limestone 24 ft., compare quartz sandstone at Marinette at 260–275 ft.	75
Wisconsin Trenton (Platteville?), blue shale and limestone	41
Blue shale 4 ft., black limestone 141 ft., limestone 19 ft., blue shale 4 ft.[1]	

[1] By a numerical slip in the *Annual Report* for 1903, p. 132, it is given as 41 ft.

At Marinette, too, the samples at 290 and 300 to 325 feet are shaly, blue, pyritiferous, and a well near Maple Ridge shows that this blue shaly base is persistent. Beneath it is a marked horizon for water. In the Neebish well, the bluish shalier base is distinct between 158 and 186 to 205 feet, but other correlations can hardly be made. I do not believe that we can yet tell where to draw the line between the Middle and Upper Ordovician on Grabau's latest plan, his Chazyan, and Trentonian-Cincinnatian-Nashvillian, nor divide into the epochs made by Schuchert, though possibly this blue shale may mark the culmination of submergence, the beginning of emergence. It is quite clear that the Trenton, as used in Michigan and generally in the West, corresponds closely with Clarke and Schuchert's Mohawkian, including whatever there may be of Chazy and Stones River (Lowville or Birdseye), Black River, and Trenton.

The section on the Escanaba River is said by Hall to be less than 75 feet (p. 144) and to include 15 feet near the top, gray, meagerly fossiliferous (p. 146). Rominger estimated it at 100 feet. But a close correlation of the various outcrops with well-sections has not yet been made. Until it is, it seems to be conservative in the matter of names.

While Escanaba limestone, suggested by Grabau, is a euphonious term, my impression is that it would be better to use Trenton, the old widely used term, in a broad sense and introduce Escanaba as applicable to some accurately defined subdivision. The triple division above suggested might perhaps be improved for paleontological purposes by transfer of a few feet. I think, however, that the occurrence of a sandy middle member, and especially a blue shaly lower, will be found widespread.

The Trenton limestone marks the culmination of Ordovician depression, when the land masses seem to have been fully buried far and near, while at the same time conditions for animal life were very favorable. As Limestone Mountain on Keweenaw Point shows the Trenton extended much farther than shown on Chamberlin and Salisbury's map (II, Fig. 129, Schuchert's map, 57 to 58). The thickness of the whole Trenton, including the Galena, is best taken from the Wagner wells (1903, p. 134) as 271 feet. The records do not indicate that it thins much to the east. Oil wells in Manitoulin

Island at Gore Bay report it 250 feet thick. I do not know any well in the lower part of the state that has gone through it, but in wells in northwestern Ohio it is said to be over 780 feet thick and in the Carmen well at Petrolia, 602 feet. While called a limestone, in this state it seems to be often dolomitic.

13. *Utica shale* (Eden of Ohio). 50–80 feet.—In many parts of the West geologists have consolidated all the shales over the Trenton as Hudson River, Cincinnati, or Maquoketa. In Michigan we seem well able to separate a black shale below, persistent and fairly uniform, varying in thickness from 50 feet at the north to about 200 feet at the south. It does not seem to be separated by disconformity above or below, and the conditions which produced it, widespread as they were, we may well expect to be universal in the sea in which it was formed. The correlations with the Utica or Eden of Ohio and Utica of western New York seem perfectly satisfactory. The base is well defined, but the line between it and the Lorraine above is not sharp and probably not consistently drawn, and may sometimes have been carried up to the Waynesville, especially as none of the wells are represented by samples every 25 feet or less. Generally the Utica and Lorraine have been grouped together and mapped with the Richmond, also as the Hudson River (Cincinnatian or Maquoketa).

14. *Lorraine or Maysville.*—We must often include with Lorraine the Richmond as well as the Maysville, which we cannot sharply separate from this or the Medina. The beds are abundantly fossiliferous, and their correlation with the "blue limestone and marls" of the Cincinnati and "upper beds of the Hudson River" is attested by Hall, Winchell, and Rominger. The Wagner well shows for the blue beds 150 feet and more, the Pickford well 215 feet, and the breadth of the belt assigned to the Lorraine and the Utica on the maps with a dip of 40 to 60 feet to the mile would indicate 350 to 450 feet. They probably thicken rapidly to the south at first, as Cheboygan well would indicate over 343 feet, while on Manitoulin Island there is but 285 feet between Niagara limestone and Trenton. At the south end of the state the records indicate about 600 feet of shaly beds to be divided between the Utica, Lorraine, Richmond and Medina, say 200 feet Utica, 250 Lorraine, 150 Richmond and

Medina. The Lorraine, therefore, appears to be fairly uniform in thickness throughout the Lower Peninsula except at the extreme north end, where it may have been eroded. The Cheboygan well shows largely limestone. The line at the top is quite uncertain. I may have included beds corresponding to the Indiana Richmond.

15, 16. *Richmond and Medina transition beds.*—This is the period of deposition of coarser matter and residual red clays formed from limestone during a period of continental uplift. Ulrich[1] would class the Indiana Richmond with the Medina and the whole group not with the Ordovician but with that above. I do not doubt that he is right. There is, however, a convenience in grouping it closely with the shales below, since it is often lumped together with them in oil-well drillings. If formed in a period of continental uplift we need not expect to find it spread so far onto the continental shield. Except for a few (26) feet doubtfully assigned to the Upper Medina by Holt and Winchell, it has not been recognized in outcrop, nor was the characteristic red facies noted in the Pickford well. At Limestone Mountain the interval from Trenton to Niagara is not exposed, no Medina has been found. The Cheboygan well shows that though absent or nearly so along the outcrop it increases rapidly to the south, since Alden and I would assign to the Medina the beds pierced by that well about 142 feet of red and green shale. During this period, Richmond to Medina and Clinton, there was a relatively ample supply of iron to the sediments, as the Clinton ores (found in Wisconsin also) show. Cummings has recently described the different horizons in southern Indiana very carefully[2] and agrees with Ulrich that the later Richmond represents the Medina, the culminating of an uplift. With this, Michigan facts are entirely in harmony, though Schuchert brings in a big oscillation in the Richmond for which I have not noted any evidence.

In wells of the region near Ohio, red beds at this point of the column can be identified, but what is noteworthy and significant, the records do not closely correspond. For instance, at Monroe 685 feet and at Toledo 675 feet above the Trenton is the last distinct dolomite sample (Clinton ?), with red and green shales below, whereas

[1] *Science* (1909), 630.

[2] *Thirty-second Report Indiana Survey* (1907), 621, 687.

at Strasburg a few miles off at 534 feet only above the Trenton is dolomite with a very red rock beneath it. No such rocks are clearly identified in the wells in the southwest part of the state, and probably were never deposited. A simple explanation would be that there was some erosion of the underlying formation here as well as along the north border and that the red and the marine part of the Medina was much restricted. Grabau has suggested that these red beds are not marine and includes the Medina as Clinton. There seems, however, to be a gradual transition from the beds below, rather than sudden uplift. Moreover, why, if wholly land beds, should they be restricted to the center and lower parts of the basin?

SILURIAN (ONTARIAN)

Some part of the beds just described may be Ontarian, as Ulrich and Cummings have said, with whose interpretation of the facts Michigan stratigraphy is in entire harmony. If so they should be classed as Medina, but as in many of the records of wells we have to include them with the shale group below, I have preferred to associate the description also.

The term Niagaran as used in Michigan includes, in mapping, Clinton to Guelph. In sections it has been used also in a slightly narrower sense, not including the Clinton.

Bigsby (1823) used the term Manitoulin limestone in an equivalent sense, giving its lithological character, organic remains, and geographic position clearly, but while he very clearly distinguished it from the St. Joseph (=Trenton limestone) and the Mackinaw (Dundee-Monroe=Helderberg in its original broad sense) limestones, he did not separate it from the shaly beds immediately above and below, which are indeed far from conspicuous in the outcrop. If we use the term Manitoulin, these limits may then be set to suit our convenience so long as the local equivalents of the Guelph and Lockport are not excluded.

As the Trenton marks the first, so the main mass of the Niagara (Schuchert's Louisville) marks the second, Paleozoic period of "epicontinental seas" of large transgression over the continent. The fact that Niagara is found in Limestone Mountain on Keweenaw Point, near Hazel Station of the Mineral Range Railroad, makes it

highly probable that all of Michigan at least was covered, and the freedom from land detritus makes it probable that the submergence was widespread, and that whatever land existed was low, and erosion mainly chemical. Elaborate subdivisions have never been made or mapped of the outcrops in the Upper Peninsula. Well-records, however, show toward the center facies that we may parallel with the New York Clinton, Rochester (Niagaran) shale, the Lockport limestone, and the Guelph dolomite, and besides this at least one fairly persistent sandy and water-bearing horizon, the Hillsboro sandstone.

17. *Clinton.* 0–130 feet.—It seems to have been well into Clinton time before that part of the state where now is the Clinton outcrop was submerged. While all writers recognize that the Clinton facies exists in the Upper Peninsula, Rominger does not consider it worth dividing, and none have tried to map it separately. A. Winchell makes it but 3 feet thick. On Manitoulin Island there may be 31 feet. Hall gives, p. 154, Sturgeon Bay, this section:

	5	light-gray Niagaran with *P. oblongus*	10
Possibly Clinton	4	thin calcareous and siliceous beds 6–10	25
	3	shaly and mixed beds Cytherina 15	
Possibly Medina	2	heavy-bedded greenish-calcareous and argillaceous limestone with chert nodules	6
	1	soft, brittle, greenish	20

The Cheboygan well shows some 60 feet which may be placed here.

In the southeastern part of the state nearer New York the Clinton is more surely identifiable.

The Port Rowan, Canada, well shows 75 feet under the Rochester.

Argillaceous dolomite seems to be the dominant rock. Water and gas are often struck in it under the Rochester shale. At South Bend there are argillaceous dolomites 1,180–1,300 feet. At Dowagiac a brownish-red carbonaceous limestone at the bottom (1,760 feet) may represent it. At Kalamazoo is an interesting section suggesting a land surface near 2,230 feet.

18. *Rochester shale.*—Above the Clinton a shale is generally identifiable in the records; whether it is the Rochester shale or at times part of the Clinton may be a question. Though persistent it is never very thick—usually 30 to 20 feet.

The Kalamazoo section of which there are samples is very interesting (but there is always the possibility of misplaced samples), and may mean that this part of the state was out of water at intervals up to the Louisville or Guelph epoch and that *after* the Clinton there was a minor re-emergence, as at the time of the Richmond Medina beds. The succession is the same, limestone, shale, and red beds, only on a smaller scale. It is also worth noting that the shale is "red" in the Carmen well; Petrolia, also "red rock" occurs just above this slate at South Rockwood (1,285–95 feet deep) near Detroit, and the Strasburg sample on top of the Clinton suggests emergence. Toward the end of the time of the Rochester shale then the shore-line probably passed through Kalamazoo. This is the more interesting because just southwest in Illinois[1] the Clinton is usually about as thick as in Michigan and is followed by a long break in sedimentation. Thus we may imagine that region emerging at the close of Clinton and staying so until after the Guelph, while Michigan did not emerge at Kalamazoo until after the Rochester shale and then at most during the lower part of the Lockport Guelph time only.

The peculiar feature of this time seems to be an oscillation or tilting, the Clinton extending more to the south, the Rochester and Niagara opening up to the north, and from the time of the Richmond Medina until after the Rochester shore-lines seem to have been in Michigan, with the continental shield fairly high. (Compare Schuchert, Pls. 64 to 66.)

19, 20. *Lockport and Guelph dolomites* (Manitoulin).—The Lockport and Guelph have different fossils but have never been separated paleontologically in Michigan. The upper limit against the Salina or Monroe is marked only in this way, that the Guelph is peculiarly hard and peculiarly white. One cannot absolutely depend upon the presence or absence of anhydrite as a dividing line. It is convenient at times to separate off the lower, less white and uniform part as Lockport (Louisville). The total thickness of the two at maximum seems fairly persistent and uniform, across the lower part of the state 350 to 270 feet. At the north part of the state it appears to be thicker. The well No. 2 St. Ignace gives just 600 feet, as a Cheboygan.

Extreme whiteness of the upper part, occasional sand grains

[1] Savage, *Illinois Survey, Bull. No. 8*, 108.

(1 per cent or 2 per cent, as though wind-blown) in the dolomites, and occasional beds of sandstone are characteristic all over the state.

It is exposed only in the Upper Peninsula. It forms the shore of Lake Michigan and Lake Huron in a continuous ridge which rises to the north almost at the dip of the beds, which is about 50 feet to the mile, from the lake level 580 feet A.T. in somewhat less than 10 miles to an elevation of about 800 feet A.T. Here and there it outcrops and very often the soil over it is thin.

While as a whole it is dolomitic, there are horizons, notably that of the Fiborn and Rex quarries, which run nearly pure calcium carbonate. They probably occur in the lower part beneath the Guelph.

The absence of sediment and the absence of iron and the fact that it is succeeded by a salt series suggests that the climate was not a very rainy one.

21. *Salina* (or Lower Monroe).—The term Monroe was introduced by me in 1893[1] to 1895, and as at first used without definition did not include all the beds down to the Niagara. In my later and more formal definition (Vol. V) I made it practically include all the Silurian above the Niagara, having found it impracticable to separate the Salina from the beds above. The difficulty still remains. The last salt bed is not always at the same horizon.

According to Grabau, there should be a marked hiatus and disconformity between the Niagara and the next overlying beds in Monroe County. The thickening as we go north, which is rapid and very great, would then be practically by addition at the bottom of beds formed during this disconformity.[2] Now, comparing wells at Britton, Milan, Romulus, and Wyandotte we do find an increasing thickness, and five feet of rock salt at Milan seems to be almost directly above the Niagara, whereas in Wyandotte there are 275 feet of dolomites below the rock salt and above the white dolomite. The rock salt at Milan is 717 to 722 feet below the base of the Sylvania, and *may* be continuous with a bed of 790 to 900 feet below it at Wyandotte, 1,080–1,190 or 1,235 feet. Again, as we go north the salt beds seem to occur higher up. Gypsum (anhydrite) certainly occurs

[1] *Report* for 1891–92, 66.

[2] *Bull. G.S.A.*, XIX, 554. Compare also Schuchert, *op. cit.*, Pl. 68.

above the Sylvania, and it is not very easy, though it may be possible, to separate off a part of the Monroe as Salina. The thicknesses given by Grabau for the Monroe below the Sylvania add up 500 feet. Salt occurs below the Sylvania usually within 450 feet. To the southeast on the Cincinnati anticlinal the salt disappears.

It is difficult to draw the upper line of the Salina in cases where no salt exists, and that is the excuse for considering the Salina as perhaps Lower Monroe. We have only lithological grounds to identify it with the New York Salina, and it is altogether unlikely that the top can be drawn consistently on such grounds. One can go only 400 feet below the Sylvania sandstone if present and then take the top of the nearest salt or gypsum bed. This gives fairly consistent results.

In the southwest part of the state, where no rock salt occurs, and all the Dundee and Niagara together do not amount to the Upper Monroe alone on the east side of the state, there was perhaps more elevation and more exposure to erosion.[1] The samples from 1,490 feet to 1,730 feet at Kalamazoo represent the Upper and Middle Ontarian and are dolomites with more or less anhydrite and quartz and *some red clay* at 1,650 feet.

Now if here was, part of the time, shore for land southwest, we should expect to find still less deposition at Dowagiac. I am inclined, therefore, now to raise the Niagara at Dowagiac even more than I did over Wright in Vol. V, to wit, up to 1,100 or 1,135 feet, taking in all the light limestones. The Dowagiac Monroe would then be only 100 feet (1,000–1,100) dolomite with 10 to 30 per cent anhydrite and quartz. If so, then the Niagara would come in the white limestone at the base of the Niles well and the Monroe between 625 and 985.

The outcrops near Milwaukee—the Waubakee dolomite of Alden, Lower Helderberg of earlier writers—are probably higher than Salina. At Ludington and Manistee, however, rock salt was struck, but apparently there is but one layer.

There is some question about a Ludington well put down by J. S. Stearns, with samples suggesting the absence of the Dundee there, and the presence of the Salina. But this agrees with Schuchert's Plate 75, and as we find over across the lake at Milwaukee

[1] Schuchert, *op. cit.*, Pl. 69.

the Traverse and Monroe (Milwaukee and Waubakee of Alden) represented, and not the Dundee or Corniferous, it is more natural to suppose the Dundee absent here also. The irregular red and rusty character of the Dundee samples at Manistee and the way it varies in the wells also suggests a deposit near shore frequently interrupted by disconformities.

Of the Frankfort well no samples have been kept, but I am told that the wells were put down deep enough to have reached the Niagara (1,800–2,200 feet) without striking rock salt and without reaching a very strong brine. So that it is likely that this was just outside the Salina sea like Milwaukee, while Ludington and Manistee were just inside.

St. Ignace and Cheboygan wells showed the New York Salina red and blue shale facies. We have therefore good reason to believe that at the close of the Niagara or Guelph the sea-level fell so that all of the southeastern portion of Michigan was above it. This begins the emergence between the Silurian and Devonian. If the salt deposits were laid down as a non-oceanic Caspian sea, we may suppose red shales like those of St. Ignace were deltas of a stream that fed it, and that the inland sea extended to the New York Salina where were other deltas from Appalachian streams. The bottom of the Salina sea should, however, have been below sea-level, like the Dead Sea at present, for we find just after Sylvania time, and at the beginning of the Devonian, incursions of ocean water and animals. Now, the top of the Niagara below this is not less than 1,200 feet at Wyandotte, and below the top of the Salina 700 or 800 feet. If then the top of the Niagara at Wyandotte was above sea-level after the Guelph, either the continent was raised something like a thousand feet, or there was warping of the crust during Salina. There was warping of the crust during the Upper Monroe, and since, but not, I think, enough to alter the fact that Lower Michigan has been permanently a basin. Any such emergence of the continent should have left traces in the sediments derived therefrom, sandstone or red shales derived from residual clays. No such beds are known to me. The Salina appears to me rather the result of but slight emergence, which grew more marked but irregular during the time of formation of the top of the Monroe.

As shown by various records, the Cincinnati anticlinal had formed and was out of water and divided the Salina sea[1] into two basins, connected perhaps by a channel through Canada between Goderich and Petrolia, north of Wallaceburg and Port Rowan, the one the New York basin, the other the Michigan.

The earlier salt beds appear to be heavier. A great many records report salt coming directly on top of "lime." Now this does not mean much, for without samples and careful observation one cannot discriminate limestone, dolomite, and anhydrite (anhydrous sulphate of lime). In many cases where samples have been saved, under the salt comes anhydrite and a good part of that which is reported as lime is really anhydrite. But in some it appears as if salt really did lie directly on dolomite. An explanation is suggested in my report for 1908, dependent on a supply of alkali water replacing the base calcium by sodium, making sodium chloride more likely to precipitate but retarding precipitation of calcium sulphate.

22. *Lower Monroe.* Bass Islands Series. 365–500 feet.—This is a series of dolomites with beds of oölite like those around Great Salt Lake, as Sherzer has shown. The cessation of salt-making may simply show that the climate had so changed that there was enough of a supply of water to keep the more soluble chlorides from forming. Or there may have been some light crustal shifting opening an outlet. There is in Michigan no sign of structural break between this and the Salina.

Grabau subdivided as follows, provisionally:[2]

d.	Raisin River dolomite, zone of *Whitfieldella prosseri* with oölite zones	200 ft.
c.	Put-in-Bay dolomite, zone of *Goniophora dubia; Leperditia* also....	100 ft.+
b.	Tymochtee beds? (Winchell Ohio).....	100 ft.±
	Relations unknown; quite likely equivalent to some other division, shaly and thin-bedded	
a.	Greenfield dolomites, Northern Ohio.....	100 ft.±

The fullest lithological descriptions are given in the Monroe County report by Sherzer, VII, 46–100. Fossil lists are given by Grabau, *Bull. G.S.A.*, XIX, 545–49.

Oölite and sandy dolomites and dolomites with anhydrite which is primary, acicular or gashed dolomites in which the hollows were,

[1] Schuchert, Pl. 70, somewhat modified.

[2] *Bull. G.S.A.*, XIX, 554.

as Kraus has shown for Monroe County, probably filled by (strontium sulphate) celestite, are characteristic rocks both in Monroe County and in the Upper Peninsula. A series of wells at intervals of but a few miles at most have penetrated this series from the Ohio line to Port Huron. It outcrops and is exposed again near St. Ignace and Mackinaw City and the islands north of Beaver Island. It probably touches the Wisconsin shore near Milwaukee, and is reached by a series of deeper wells along the western side of the state. A list of locations will be found in the report for 1908.

As the total thickness from the base of the Sylvania down to the salt shown in numerous sections runs only from 337 to 400 feet at the outside, Grabau's estimates of the thickness of the subdivisions cannot be added. It is very often impossible to make lithological subdivisions. A bed of sandrock often occurs under the main Sylvania sandrock a short way. The Waubakee dolomite fossils in Wisconsin most suggest the list of the Raisin River and Put-in-Bay beds, and I think there is reason to believe this series more widespread and persistent than the series above or below. The salt series below certainly does not extend so far either to the south or to the north. To the southeast down in Ohio, where the Sylvania sandstone is very thin and the overlying beds between that and the Devonian limestones easily overlooked, this lower Monroe is still persistent. The fossils reported from Milwaukee and from the Upper Peninsula by Rominger[1] are Lower Monroe rather than Upper Monroe forms.

Finally as we trace the beds from the thinner "Helderberg" or Monroe sections of Indiana toward the thicker sections, between Algonac and Alpena, the addition seems to be of beds above and below to a nucleus of Lower Monroe which remains fairly uniform in thickness. But there is this difference as we trace the section north along the Lake Michigan shore from that which happens as we go east toward the Cincinnati anticlinal. In the former case the Traverse (Hamilton) thickens, but very little is seen of the Dundee beneath—between it and the Monroe—in fact, there does not appear to be much added to the Monroe itself. The explanation would seem to be that for a good part of the marked erosion intervals (Waubakee or Helderberg) between Niagara and Monroe and again between the

[1] *Michigan Geol. Surv.*, I and III, 28.

Monroe and the Traverse (Milwaukee or Hamilton) the east or Michigan side of Lake Michigan was out of water and the Wisconsin post-Niagara uplift was fairly uniform from south to north. On the whole, the south seems to have been first to emerge (since there is more Niagara at the north and the seaward opening was to the north). The Salina sea was left to deposit salt. The recession or submergence during the Monroe may have been uniform. Whether the next emergence began sooner at north or at south one cannot tell since there is so decided an erosion unconformity.

A small percentage (1 to 5 per cent) of sand found in the Monroe dolomites may have been wind-blown from exposed beds of sand in Wisconsin. Passing northeast we find the Lower Monroe persistent. I am inclined to think, therefore, that the Michigan seas of Schuchert's Upper Siluric maps should open to the north much more.

At Port Huron the Lower Monroe is (1,215–1,555 feet) 340 feet and making a considerable jump to Goderich, Canada, we find between the limestone group and the salt 364 feet. This persistent thickness is an argument that between Monroe County and Goodrich was continuous deposition and that we have a complete section here. At Grand Lake in the Alpena Land Co.'s well, we find the limestone coming down somewhat farther and very thick. At Alpena the whole Monroe appears to be only about 713 feet, but there are discrepancies in the depth at which salt is said to occur at the different wells around Alpena that may be due to dislocations of the Monroe before the Traverse.

There seems to have been a pre-Traverse dip from Alpena north, enough to counterbalance the present Traverse dip the other way and in that direction was limestone and the open sea.

To the east then the submergence of the Monroe was longer, the emergence at the close delayed, and as we shall see, intermittent, and a land-mass formed to the south during the Upper Monroe.

23. *Sylvania sandstone.*—30 to 440 feet thick as sandstone, 170 feet as limestone. This, the Middle Monroe formation, is easily described. It has been found only along the flank of the Cincinnati anticlinal as a well-defined bed. It thins toward the outcrop where it is between 50 and 100 feet thick. It is thickest in a line through Milan, Ypsilanti, and Royal Oak. It probably skirts the Cincinnati

anticlinal rather narrowly, for it is relatively thin at Britton, Ann Arbor, Mount Clemens, absent at New Baltimore, though present at Port Lambton and Marine City, and absent at St. Clair, but present at Port Huron.

Grabau and Sherzer are inclined to consider it aeolian. But the way the grains of sand occur in the dolomite or limestone as in Port Lambton (and in a series of records like those at Marine City [Vol. V], we find it shading into the dolomites) its fairly regular variation in thickness, similar at similar situations[1] on the Cincinnati anticlinal, growing thicker to the line of thickness above mentioned, suggest that if they were wind-transported they were water deposited. Of course, near the outcrop it may be more aeolian. Lithologically it is a pure (99 per cent) quartz sand of the highest grade of glass sand as white as sugar. The nearest like it of recent sands that I have found is one from Florida. Its extreme freedom from iron is not characteristic of desert sands. On the other hand, it seems to have a characteristically fresher water (stronger in sulphates) than the beds below.

The disconformity with the beds below which Grabau mentions is not marked, though there are red sandy-looking beds at about that horizon in a few wells. The disconformity above is most marked and, as Grabau has pointed out, a new fauna appears of puzzling affinities. It seems that in many places during the whole time of the Lower Monroe and the Middle Devonian the American continent was out of water, and the disconformity marking this period of emergence is the well-defined and accepted line between the Silurian and Devonian. This applies to Milwaukee and western Michigan. But the great basin of Lower Michigan was not lifted altogether out of water. The warping which caused the emergence lifted up the Wisconsin land-mass and also the Cincinnati anticlinal, and the Sylvania sandstones were formed as emergent sandstones along a shore not altogether unlike those from Chicago around to New Buffalo today. It was partly aeolian, but there is reason to think that much of the wind-blown sand found its final resting-place under the water, building a sandy shelf out from the shore.

[1] Compare Dundee, 60 to 253; Morton Salt Co., 65 to 262; Solvay, 95 to 415; Wallaceburg, 100 to 1,100; Port Lambton, 50 to 1,250.

But the emergence this time was not a mere recession of the sea-level. There was an Appalachian warping and gentle folding extending clear to Michigan, for as Grabau has pointed out, not only is there a disconformity of the Sylvania and overlying beds, but both together were folded and eroded before the Upper Helderberg was laid down, both around Alpena and to the mouth. One result of this was to permit an incursion from somewhere (judging by the thickening of the limestones from north of Alpena) of the first Devonian-looking fossils known, as described by Grabau. He tells me the same things come from the Saskatchewan.

It seems clear, comparing the records of the various wells, that to the northwest the Sylvania is replaced by a series of limestones.

Take the large group of wells at Marine City reported in Vol. V. In all of them at about 1,000 to 1,100 feet down, and about 500 to 600 feet above the first salt, 300 feet or so above a well-marked gypsum bed (which may be really the most fitting place at which to draw the top of the Salina) we find from 60 to over 100 feet of sandstone, often calcareous and passing into a sandy limestone or arenaceous dolomite, like the top of the Lower Monroe Raisin River beds. The same horizon is plain in New Baltimore 940–1,275; St. Clair 1,050–1,270, and Port Huron. There can be hardly a doubt that this corresponds to the Goderich Group III of Hunt, and so presumably to the Sylvania and part of the Upper Monroe. As usual *passing from the outcrop the unconformities* seem less. In its limestone facies it is impossible so surely to assign a thickness, but it seems to be about 170 feet. How much of this should be attributed to a thickened base of the Upper Monroe is a matter for further research. The fairly uniform thickness for Middle and Upper Monroe from Lake St. Clair to Alpena suggests no appreciable disconformity in this region. So far as one can judge the Upper and Middle Monroe are absent on the west side of the state. Even around Mackinaw and at Cheboygan there are no indications of them known to me. They are not shown on any of Schuchert's maps. I am not so sure they should not be placed on Plate 72.

24. *Upper Monroe.* Detroit River Series (275 ft.).—This series seems to have been deposited in a long, narrow trough at the very end of the Silurian at a time when most of the continent was out of

the water and much progress had been made toward the evolution of the Devonian forms. Just as in New York higher and higher horizons of the Eo-Devonian rest to the west on the Salina and water lime, so in Michigan to the southeast and south higher and higher horizons of this formation rest on the Sylvania. It is also true that the Corniferous or Dundee rests on various members of this. The Corniferous (Onondaga) above is unquestioned Devonian. The Monroe below the Sylvania will, by general consent, be classed with the previous period. But the Sylvania has often been called Oriskany and the fossils of beds above are remarkably like Hamilton forms, while the very top of the Lucas dolomite has been generally taken to be below the Devonian.

If, with H. S. Williams, we place the base of the Devonian at the Oriskany and class the Lower Helderberg beneath as Silurian (Ontarian) as used to be common (compare the 1892 edition of LeConte with the latest) we can then surely place the whole Monroe with the Silurian as I did. Canadian writers have generally grouped the Sylvania as Oriskany.

But beneath the Oriskany comes the Lower Helderberg series of New York 300–400 feet[1] and Pennsylvania 600 feet, and in Europe stages E and F, and the relation of these to the faunas is a complex problem of paleogeography. After the Salina (all up) was there a see-saw—first the Michigan trough down (Upper Monroe), then up, and the New York Helderberg down? This is the view accepted by Grabau. Or is it possible that at the time of the Sylvania the Michigan basin was so separated from that of New York that the two could have separate faunal developments at the same time, the New York receiving precursors of the Corniferous, Michigan of the Hamilton, while somewhere around there lingered relics of the Silurian faunas which re-established themselves when the old anhydrite- and dolomite-forming conditions returned in Michigan? This would imply that on Schuchert's Plate 72 a long sound of Upper Monroe should extend, opening to the north.

On the whole, the greater break as well as the most widespread, and therefore the one best fitted to mark the beginning of the Devonian, seems to be that above the Detroit River series. For there

[1] Schuchert, *Bull. G.S.A.*, XI (1900), 270; XX.

appears to be not merely a disconformity as between the Detroit River and the Salina but an actual unconformity, so that the Detroit River beds were folded before the Dundee and Traverse were laid down. Such a folding is indicated by the fact that while at Alpena there is[1] a dip of the surface beds 42 feet to the mile to the southwest this does not seem to be the case for the lower beds of the Monroe. The salt is as deep to the north. Again, along the St. Clair River in the Devonian there is an anticlinal near Port Huron where the oil wells are in the Traverse (Hamilton). But the Monroe beds do not follow this fold The salt runs more nearly on a level. Again, around Detroit in Wayne and Monroe counties, Grabau has described how the Dundee of the Devonian lies on various beds of the Monroe. For the present, therefore, it will be well to keep the line between Devonian and Silurian as heretofore and as Grabau wishes, remembering that with the line so placed, a very Devonian-appearing fauna already existed during the time of the Detroit River beds, and that, as in New York, between the Helderberg and the Oriskany[2] there is an unconformity and a more marked one prior to the Cobleskill Rondout, so it is with the Detroit River series, which from a structural point of view is closely allied to the Helderberg.

At the salt shaft, and near by, the subdivisions are, according to Grabau and Sherzer:

146		
	180	1. Lucas dolomite (with Cylindrohelium profundum) (200 feet+) with sulphur and gypsum.
326		
	9	*c.* Amherstburg dolomite (with Panenka canadensis) transition to Lucas—20 feet.
335		
	38	*d.* Anderdon limestone (with Idiostroma nattressi and a fauna like the Hamilton).
	40	50
373		
	47	*e.* Flint rock dolomite (with Syringopora cooperi).
	50	
420		150 feet+.....
		Sylvania sandstone beneath.

[1] *Report* for 1901, 67, and Pl. VII.

[2] See Grabau, *Geology and Paleontology of the Schoharie Valley*, 179; *New York State Museum, Bull. 92.*

It is next to impossible to trace these largely paleontological subdivisions in the wells, especially the difference between Amherstburg and Anderdon. But the tendency to a dolomite top, with sulphur reduced from gypsum and anhydrite, and limestone lower can be plainly followed.

Above the undoubted Lucas either as an extension of the base of the Dundee or as a still higher member of the Detroit River series (which it would be interesting to compare with the New York Helderberg) was an intercalation of limestone in the Lucas which did not reach as far as New Baltimore. By the time we get to Alpena, limestone occurs at various horizons. There is clearly a tendency to replacement of dolomite by limestone toward the north in the direction probably of the open sea. The Michigan Monroe seems to have been, like the Black Sea and Caspian, turned northside south.

At the close of the Monroe the state was so elevated that slight folds which occurred at the same time could be planed off, and the underlying formation in numerous places from Mackinaw to Monroe County, made into a dolomite conglomerate, calcirudite. So far as we know it remained above water during the opening stages of the Devonian Helderbergian. There is distinct reason to believe that *this* uplift was not a mere rise and fall of the sea strand produced perhaps by disturbances thousands of miles away like the earlier changes in Niagara time, but a tilting by which the west was more elevated than the east and a certain amount of folding took place. The Limestone Mountain fold on Keweenaw Point may have taken place this early. The Sylvania uplift seems to have been decidedly most at the south, opening up and depressing the land at the north. By the close of the Amherstburg the effect of a new uplift made itself felt in cutting off the northward connections and the conditions for formation of dolomite and anhydrite were re-established and with them the Silurian fauna. The same disturbance that cut Michigan off once more may have opened up New York to the Helderbergian, so that while the Coeymans and Port Ewen beds were forming in New York, 300 or 400 feet in all, Michigan was mainly out of water, and not until the Schoharie (Hall in Foster and Whitney, II, 225), did deposition that has been recognized by its fossils begin in Michigan.

DEVONIAN

25. *Dundee limestone.* 200 to 253 feet.—This formation—the Corniferous or Onondaga nearly—is full of fossils which have been described by Hall, Winchell, Rominger, Schuchert, Grabau, and others.[1] On the east side of the state between the blue and black shales that may represent the Bell or Marcellus and the first dolomite, which seems to be generally the top of the Silurian (of course, there may be a puzzling dolomite conglomerate at times) the formation can be traced persistently. It is very uniformly a high-grade limestone with only a small percentage of magnesia, not infrequently over 98 per cent $CaCo_3$, light colored, or brown with oily matter, containing a water relatively high in sulphates, relatively weak and strong in H_2S, and generally hard. It is sometimes, not always, cherty or "corniferous." Beginning with a thickness of an even 100 feet in the southeast corner of the state, it thickens slowly to Port Huron. Going west and north it at first thickens until it gets its full thickness of about 250 feet, and then begins to thin, as I now believe.

For instance, the Niles well on p. 280 of the report for 1903 may be interpreted as having only 12 feet of Dundee and then entering the Monroe, and that in Vol. V as (the Oriskany being at 540 feet) having but 40 feet, and all these wells in the southwest corner as striking through from some part of the Traverse corresponding to the Alpena limestone into the Monroe, the Dundee being omitted, agreeing with Schuchert's map, Plate 75.

As we go up the Lake Michigan shore northward it is apparent that the Traverse expands to the thick 600-foot section found in its northern outcrop, while the Dundee does not increase so much. The top thirty feet and other places are sometimes quite sandy and often cherty. It is not often sandy on the dividing line between it and the Monroe.

Throughout my work in Vol. V and the annual reports I have considered all the Dundee as a limestone and this has given consistent results. Four miles east of Mackinaw City, in a section where I thought I found the Dundee directly overlying magnesian limestones of the Monroe, Grabau found in the top layers of the magnesian beds a

[1] *Annual Report* for 1901, and *Bull. G.S.A.*, XVII (1901), 719.

typical Schoharie fauna, agreeing with Hall's determinations on Mackinac Island 50 years earlier. We must then grant the occurrence of magnesian beds near the base of the Dundee. It would be strange if overlaying a magnesian formation the base were not magnesian. The paleontological and structural dividing line may be a few feet beneath the lithologic line which I have had to use.

26. *Traverse* (Hamilton and Marcellus, Erian of Clarke and Schuchert, Delaware[1] of Ohio). 600 feet.—As this group is much thicker and better exposed in the north end of the state and its very existence along the south line of the state has been doubted, we begin our description from the north where it outcrops on Grand and Little Traverse Bays, and thence is frequently exposed around to Alpena and Thunder Bay, and is nearly uniform in thickness (600 feet with a basal shale, Bell shale, 80 feet, which corresponds to the Marcellus and is persistent throughout the state).

Grabau gives:

Chert beds.....	45–50	Naples goniatite fauna at top
Petoskey limestone.....	360	Stromatopora and buff magnesian
Acervularia beds.....	110	Bryozoa beds
Bell shales.....	80	
	600	

When we get to Port Huron, nearer the Cincinnati arch, it seems to have shrunk to 330 feet or so. Thence down to the Ohio line it tends to shrink especially toward the axis of the arch. But the *marked black or blue shale base persists.* Hence there is reason to suspect that the loss is mainly by removal of the top. This would imply that our early Traverse is Schuchert's late Hamilton, Plate 76. There is a fairly persistent division to which the drillers apply customary names.

Cooper's 2. Petoskey limestone. The "top lime" 85± (sometimes pyritic at its top).

Cooper's 3. The "top soap rock" 150±.

Acervularia beds. "Middle lime" 4–15. Never thick, but persistent, the Encrinal limestone?

Bell shales? "Bottom soap rock" 65. Darker than the other.

[1] Sandusky has been discarded.

There is good reason to suppose that during *late* Traverse there was some emergence, while the line between Dundee and Traverse does not appear to be marked by a notable unconformity in Michigan. We find also in New York the closest affiliation in deposition between Onondaga and Marcellus. The supposed unconformity at the top and maximum depression at the base of the Traverse is in harmony with the description by the Wisconsin Survey (ii, 397) of the beds there as early Hamilton.

27. *Antrim shales.* (Senecan, Genesee?, Portage and Chemung of New York, Ohio) Huron, Chagrin, Cleveland, and Bedford. 480 to 140+ feet.—There is good reason in the thinning of the formation and in the irregularity and reddening of the top to believe in an elevation south of Michigan toward the close of the Traverse (Hamilton). But in Iowa, too, the Upper Devonian is said to be unconformable on the Middle. At the base of the Antrim shales on Thunder Bay, Grabau found the Naples goniatite fauna which would imply, perhaps, that the Antrim black shales though lithologically like the Genesee were really somewhat later, and the Genesee missing.

This horizon is struck very widely. The full thickness is not less than 340 feet. In order to get consistent results and thickness one must recognize that the transition to the Berea Grit is gradual and a great thickness of Berea Grit or strata ascribed thereto is at the expense of the Antrim. The Antrim consists mainly of shales, black and bituminous at the bottom, then blue, and at top, where it passes into the Berea Grit, or the horizon thereof, red or interstratified with sandstones and gritty.

To put the base of the Carboniferous at the base of the Bedford we should have to split the Antrim in a very impracticable way, though we could readily enough follow Ulrich's suggestion and place it lower. It is noteworthy that just as the Sylvania is confined to the east side of the basin along the Cincinnati anticlinal, so is the Berea Grit, and when the Berea Grit does not appear, then the upper strata of the Antrim have a red facies like the Bedford of Ohio, or the Richmond top to the very similar Lorraine. This red facies is, it seems to me, very likely due to exposure to the weather. Where the Berea Grit is *well* developed it is, I believe, never found. It,

therefore, may indicate the uplift generally taken to mark the close of the Devonian and beginning of Carboniferous. The upper part of the Antrim is blue rather than black and frequently there are beds of sand and grit. There is generally at least 100 feet of the bottom black shale, but since the blue and black shales alternate at times, records may or may not show the Cleveland Chagrin and Huron as one solid black shale, or may overlook the Cleveland and count everything down to the Huron as blue shale.

MISSISSIPPIAN

28. *Berea Grit* (or sandstone[1]). 273 feet.—This is an Ohio formation and has never been seen at the surface in Michigan, but may be traced very well along the flanks of the Cincinnati anticlinal, from near Adrian north. Westward it seems soon to disappear and to be spotty in occurrence. Eastward it may well have once been continuous with its Ohio outcrops. Continuous past Ann Arbor and Pontiac and Birmingham, Romeo, Utica, and Berville to the southeast corner of Sanilac County it may be followed around the Thumb in wells put down to tap its brine to Bay City. From Bay City it may be traced north to Harrisville, near which it comes to the under surface of the drift. It thickens gradually from about 40 feet until it is thickest near its western margin (over 300 feet). Then it disappears suddenly. The brine is exceptionally salt, even near the surface, and unusually free from sulphates.

The sandstone is generally fine grained, micaceous, and overlain by a black shale (the Berea or Sunbury shale).

Now, if we take the Alma, Bay City, and Caseville wells and figure from the top of the Marshall as a datum we shall have the form of a deposit formed along a shore facing east and running nearly north and south through the center of Michigan (compare Schuchert's Pl. 78). It is also true that it is coarser where it is thicker and not so pure—more of a fine-grained grindstone to the east.

This points to a marked line between Carboniferous and Devonian. We have something like the same question that arises as to the red Richmond shales mentioned above, but there is a marked difference in that above the Berea Grit we do not pass into limestone like the

[1] Compare Oneonta Chemung and Catskill.

Clinton limestones, but back into black shales, like the base of the Antrim, the Berea, or Sunbury shale.

I am inclined to believe there was originally less sulphate in the brine and that would point to a less arid climate,[1] and with that the black shales and greater abundance of mud are in agreement. At any rate the Berea Grit seems to mark an episode apart from any *great* climatic change.

29. *Coldwater shale.* Part of old Waverly; Sunbury or Berea shale, plus Cuyahoga (which includes Buena Vista), plus Raccoon and part of Black Hand, perhaps; Orangeville and Sharpville? 1,000 feet.—The next series lithologically corresponds to the New York Portage and Chemung and is one largely of shales, which generally make valleys in the bed-rock surface and in a state so heavily drift laden as Michigan are rarely exposed. In Ohio there are two or three distinctions clearly made. The thickest, most carefully studied, and best exposed section is that of Huron County,[2] as follows:

Blue and sandy shales of Willow River and Secs. 2 and 3, Huron Township	172	
Black Hand of Ohio? in part		
Light House Point conglomerate, Herrick's I, Large fauna	4	176
Directly under should come the Raccoon, Herrick's Waverly shale fauna.		
Blue shales with carbonates of iron of Port Hope, Harbor Beach, White Rock to Forestville, with *Chonetes scitulus*, cf. pulchella, common throughout	720	896
Black Sunbury shale with *Lingula melie* and *Oroiculoidra newberryi* in Ohio	103	999
practically an even		1,000 feet

The black shale base is very persistent when the Berea Grit comes beneath, and continues as at Alma and Grayling, even beyond its limits and is presumably the equivalent of the Sunbury or Berea black shale of Ohio. Like that it is a persistent and widespread horizon whose thickness is generally only 25 to 55 feet, averaging about 40. It is clear that in well records there must be some uncertainty as to whether we are dealing with the red Bedford or the red

[1] See analyses in Clarke's data of geochemistry.

[2] Vol. VII, *Geol. Surv. of Mich.*, Part 2, pp. 18–27, 247–52, Pl. I.

top of the Sunbury in wells where the Berea Grit itself is absent. In the extreme western part of the state, as at Dowagiac and Constantine[1] (one well only) less than 20 feet of red shale has to do duty for Bedford to Sunbury, and the Antrim beneath is thin. I think the red shale is the weathered top of the lower formation. It is conceivable that the Berea Grit once extended farther and has been eroded away. On the whole, however, it seems more likely that while the whole period Bedford to Sunbury was one of elevation, there were two times when the shore-line advanced farthest east—one just before the Berea Grit, one just after the Sunbury shale, correlative to the Buena Vista flags.

There has been a question as to whether it would be better to cut the Berea or Sunbury shale off from the Coldwater. But it was included in the original definition of Coldwater and has been recognized in Michigan only lithologically. It would seem best for the present to keep the term Coldwater as originally introduced to cover the interval from Berea Grit to Marshall, and use the Ohio terms Sunbury and Cuyahoga, Buena Vista and Raccoon for fitting subdivisions when possible.

Brines and sandstones seem to appear not really at the Berea Grit level but somewhat above, but correlations are largely guess work, as all of these sandstones are readily overlooked by drillers on the one hand, and none of them are thick, and sandy, salty streaks are liable to occur at various levels without question. Hard streaks are also liable to occur which are largely bands of iron carbonate, or they may be huge round kidneys, such as are known to exist.

The outcrops of the Coldwater were described by the first Geological Survey, Hubbard, and others, by Winchell in a long series of papers,[2] and by Rominger,[3] who calls it and the Marshall, the Waverly Group. It covers a considerable area.

On the western side of the state the Upper Coldwater (or possibly the Lower Marshall) about 300 feet below the top or 700 feet above the bottom becomes distinctly more of a limestone. At least that is one way to interpret the records.

[1] *Annual Report* for 1903, 281, 282.

[2] *Biennial Report*, 1860. See also Weeks in *Bull. 191* on Marshall.

[3] Vol. III, Part I, chap. viii, 67, 75.

Alma has sandstone, black shale, and limestone between 1,575 and 1,740 feet, i.e., 560 feet below the top of the Marshall, corresponding to Bay City 1,630 feet in the well of Vol. V (Atlantic Mill), 750 feet in the South Bay City well. This we may strongly suspect includes the upper part of the Coldwater down to Herrick's conglomerate 1, the Black Hand and Raccoon.

In the Charlotte well from 570–680 feet is sandrock, from 680–1,150 appearing to be shaly limestone, if the samples are representative. There are 350 feet below down to the Berea horizon. So at Jackson is a salty rock at 660 which, in Vol. V, I took to be the Napoleon, but I am quite sure that I was mistaken. This would seem to be an appearance of the Michigan series, or rather a Kinderhook facies and an incursion of the western Carboniferous during the Coldwater. It looks as though at about this time (that of the Coldwater and Marshall) the eastern side went up, the western side down, and that corresponds with what is known of the continent in a large way.[1]

The abundance of goniatites in the sandy beach-like beds of the Lower Marshall suggests that they were open to the western ocean, and we should expect an even more Kinderhook facies in the Upper Coldwater and Lower Marshall of the western part of the state. Unfortunately there is not the slightest chance of outcrops of this calcareous Lower Marshall or Upper Coldwater, but possibly some fragments of the fauna might be identified in the drift back of Ludington.

The Coldwater is an emergent formation and gradually passes into the sandier facies of the Lower Marshall; where to draw the line will be discussed in connection with the Marshall. The Coldwater appears to be nearly as thick even if more calcareous to the west, the total for Lower Marshall and Coldwater being always a little over 1,000 feet.

30. *Marshall sandstone* (Raccoon possibly, Black Hand and Logan of Ohio in part).—This formation was extensively studied by Professor A. Winchell who, in distinction from earlier writers, recognized the Carboniferous type of its fauna, when he first introduced the term (report for 1860). He made a heavy sandstone which he called the Napoleon the base of the Carboniferous, and called the

[1] Compare Schuchert, Pls. 78 and 79.

beds beneath the Marshall, the top of the Devonian corresponding to Chemung. Later[1] his investigations led him to include this Marshall with the Carboniferous, and then he also united the Napoleon andstone with it as Upper Marshall, and finally concluded apparently that it was not worth separating but only a lentil. The whole matter is discussed in full in the Huron County report. The Marshall is evidently a case of emergence on the east first, micaceous sandstones becoming more and more abundant, and bands of carbonate of iron and fossils, while blue shales still persist in layers. At a number of places white sandstones occur and thin beds of what I have called peanut conglomerate, white quartz pebbles with heavy cement of carbonate largely of iron, which weathers brown and gives the color effect of peanut candy. The transition from Coldwater is gradual, and it is not easy to fix the line consistently. In fact there are some paleontological reasons for believing that the whole southwestern Marshall may be older than the Huron County.

The Huron County section is fullest, as follows:

Napoleon (Upper Marshall) sandstone	300	300
Lower Marshall (Original Marshall)		
Hardwood Point shales and sandy flags, fossiliferous, "typical Marshall" fauna	85	385
Point Austin sandstone	23	408
Sandy shale	68	476
Point Aux Barques sandstone	18	494
Shales and flags with Romingerines Julia	41	535
Grindstones with bands of peanut conglomerate and broken goniatite shells	25	560

The southern Marshall is thinner and since it is an emergent formation it is easy to assume that this part of the formation emerged sooner and was more eroded, and not so soon covered. The series that came after the emergence should also be less complete and as a matter of fact the Michigan series here lacks gypsum and seems otherwise less complete.

But may it not be that not only did emergence but the tendency toward emergence indicated by the sandy facies begin sooner? There is faunal indication of this.

[1] See references in Weeks, *Bull. 191, U.S.G.S.*, 260. But add also *Am. Jour. Sci.*, XXXIII, 352–56, and *Proc. Acad. Nat. Sci.*, XIV, 405–30.

A simple and natural explanation of faunal relations would be that the Marshall emergence took place earlier to the southwest than to the northeast. This does not agree with Schuchert's maps. If so, the question at once arises, must we not reverse our definition of the Lower Marshall, bringing it down to include the Raccoon shales and their equivalent in Huron County, down to Port Hope nearly, adding 200 feet to the Huron County section, and making the Marshall there over 760 feet thick? This may be the future solution of the question. Cooper leans to it. But we should be as sure as possible before making changes. So we must ask what indications are there of a land mass in this direction? Also are there any indications of a shortened geological column to the top of the Marshall in this direction?

There is a little thinning as compared with the Huron County section, but not enough, and no shrinkage as compared with the center of the basin. We have besides to allow for a dropping-out of Berea beds and for the unusual thickness of the Huron County Upper Marshall as given in the column which seems *very* local.

The limestone character of the western Coldwater is rather against its earlier emergence, as well as the relatively wide spread of the western Kinderhook.

There is an alternative hypothesis (supposing the paleontological facts to remain established) and that is to suppose that the Paleoneilo fauna of the Raccoon shales were immigrants northward that reached Ohio earlier but did not reach Michigan until later—until after the beginning of the Marshall. This seems to me the more likely because the fauna most like that of the southern Michigan Marshall that we find in Huron County is way up in the Lower Marshall at Flat Rock Point.

31. *Michigan series, Lower Grand Rapids.* Logan possibly absent in Ohio? (380—generally about 200).—The Marshall is Kinderhook of the Illinois reports. Following the Marshall there was an emergence and an interval of erosion without deposition of some time around the edges of the basin, but perhaps none near the center, for the series there is of greater thickness and its deposits of gypsum attest its cut-off character. In the Mount Pleasant well it is 358 feet

thick—the fullest of any in the state. There is always a gypsum or anhydrite bed near the middle of the formation, and with this is associated dark-colored dolomites and dark-blue shales. Sandstones are thin and irregular and in some cases there are dark limestones toward the base. These dark, impure limestones, are quite different from the Bayport limestone. The section around the margin if at all full is something like 200 feet, but from Tuscola County south to the Assyria are a lot of wells in which it is hard to recognize this or the Bayport at all. Occasionally, as around Byron, very salt water near the surface may indicate outliers of it. The water from the formation is salty and "bitter," full of calcium and magnesium sulphate and in that respect very different from the Marshall immediately underlying. The absence of the Michigan series from the southeastern part of the state seems to be due not wholly to erosion at top, but to uplift of the bottom, the emergence of the Marshall having progressed so far that this part of the state like the corresponding part of Ohio was out of water.

The date of this emergence during which the Lower Michigan was forming in the center of the basin is pretty definitely fixed on paleogeographic grounds as that of the Upper Augusts or Osage.[1] The Michigan series seems to have continued forming until a depression to the west opened connection with the wide ocean at the time of the Maxville of Ohio, Upper St. Louis or Kaskaskia and Chester of the Mississippi Valley. The section seems to be continuous without disconformity to the overlying limestone, which I have called Upper Grand Rapids, since both sets of beds were well exposed near Grand Rapids and seem in many ways bound together. The Lower Grand Rapids must then include the Lower St. Louis and probably the Keokuk and perhaps in the center strata representing part of the Burlington, the time Kinderhook-St. Louis including an era of emergency in which all of Michigan but a central sea was out of water.

The dark and sometimes even black slates and the blue and dark, impure dolomites give the formation a more muddy look than the Salina, while the general association of dolomite and gypsum is like that of the Salina, and one is inclined to believe that some land waste and rain erosion were still going on, though local conditions favored

[1] The emergence between Schuchert's Mississippi and Tennessee.

concentration and after all chemical erosion and deposit were much more important in the Grand Rapids than at any time since the Traverse.

32. *Maxville or Bayport limestone, Upper Grand Rapids, Upper St. Louis, Middle Kaskaskia.* (50 to 235 feet usually eroded).—This formation marks the culmination of a transgression.[1] Generally it is only 50 to 75 feet thick or less, and seems to be much eroded away by a heavy erosion and uplift that took place after its formation. But in the Mount Pleasant well 235 feet may belong here.

Light, hard limestones, bluish with chert and white sandstones are characteristic. It is the typical old subcarboniferous limestone. Faunally (with Allorisma, Lithostrotion canadense, etc.) it is also closely allied with the Upper St. Louis, the middle of the Kaskaskia, and the Ohio Maxville—an epoch of maximum ocean extent at this time. I do not know any good reason for not calling it Maxville.[2] Owing to the heavy subsequent erosion there is no telling how far it may have extended, but it certainly extended into Huron and Arenac counties and thence west. It also extended south of Jackson, and may once have gone into Ohio continuously.

However, in a region from Tuscola County south around Durand, Morrice, and Howell, there seems to be an area where it does not now occur and perhaps never occurred. An anticlinal uplift either prevented its formation or caused it to be eroded away. From Jackson to Grand Rapids past Bellevue and Assyria, however, there are frequent signs of its presence though the coal measures are laid upon it with a very marked unconformity.

On the whole, the climate was not one that favored the formation of shales, but limestone, chert, and clean white sandstone rather, and as the continent was sinking the rivers tended to aggrade and leave their mud before reaching the sea.

At the close of the Bayport formation the state was quite likely lifted entirely above water for quite a while,[3] since wells in the center of the basin as near to each other as Alma, Mt. Pleasant, and Midland show very different sections, and the Parma conglomerate base of

[1] Schuchert's Tennessee which he makes early Chester, Pl. 81.

[2] See *Michigan Miner*, December, 1906; *U.S.G.S. Water-Supply Papers*, 182 83.

[3] Schuchert, Pl. 82.

the coal measures appears sometimes at one level, sometimes at another. The Bayport is apparently entirely gone at Alma.

This, then, would be the line between the Mississippian and Pennsylvanian, in this state the strongest disconformity since that at the base of the Devonian, and the first time that there is any evidence that the whole of the state was above water.

PENNSYLVANIAN

33. *Parma conglomerate; Pottsville* (170 feet; basal member).—The recurrence of deposits in Michigan is marked by a bed of conglomerate. The pebbles are not always present, to be sure and are rather small and very white, about like split peas, and the mass of the formation is sandstone. The name is taken from a point on the margin of the basin which is very likely contemporary with shales, etc., in the center. As a term, then, it is, like the Potsdam, not to be taken as of definite age but as the underlying basemental and shoreward facies of the Saginaw formation. As a very persistent horizon easily recognized by the presence of pebbles, which are rare in the Michigan column, and as an economically important water bearer it deserves a place in the column. Compared with the Marshall brine beneath, it has less of the earthy chlorides, more of the sulphates.

The wells of the Saginaw Plate Glass Works yielded a set of samples which show the characteristic Parma and the strata above and below.

34. *Saginaw formation. Upper Pottsville* (400).—This is the coal-bearing series of Michigan. All the other formations seem actually to dip and occur deeper at the center than at the margin of the basin. Mr. Barnes, chief driller of the Consolidated Coal Co., thinks that for this, too, the marginal coal seams, at Sebewaing and Jackson, correspond to the deepest seam at the middle. I am hardly inclined to think it. Their chemical character is more like upper seams and the fauna and flora of the upper seams at the center and at the margin seem similar. The series is a succession of white shales (so-called fire clays) or sandstones, black shales (called slate) and coal, and blue shales, with occasional thin bands of black band ore (siderite), and nodules of the same containing zinc blende and iron

pyrites, and very rarely limestones with marine fossils.[1] More commonly, but still rarely, in the black shales a *Lingula carbonaria* or *mytiloides*, and at Grand Ledge a little pelecypod like Anthracosia occurs, and this Lingula seems to mark a definite horizon, that of the Upper Verne, the two Verne coals often occurring close together and sometimes having a limestone between.

The fauna and flora indicate Upper Pottsville (Beaver or Kanawha) near Mercer (compare the Kanawha, Black Flint, Mercer limestone and Stockton coal), and is also near the top of the Saginaw formation. How much lower the base may possibly go we have no means of knowing. But there is reason to believe that there was not continuous deposition even in the center of the basin, and the Upper Pottsville is over 1,200 feet in West Virginia.

As a whole, the formation is composed of beds of rather rapidly varying thickness and character. This is true also of the coal seams. In one mine they will rise and fall 20 feet and more, pinch out or pass into black shale. A curious feature is a local persistence of facies. That is, in one township there will be a great deal of sandstone at many levels, at another there will be much shale at all levels, in one region many of the coals will be prominent, in another none. Finding a good upper coal is by no means a sign that the coals below will be extra thin.

This points to a certain persistence of geographic condition. That is, if a big sand dune or sand bar occurred in a point flanked by a peat swamp on one side and muddy clay-depositing waters on the other, while it extended more or less widely and shifted a little from time to time, yet it tended to remain in the same general region and even built up as the general level of the water rose. We can see that this might be so by watching the effect of rises and falls in the level of the Great Lakes. A rise of 7 feet may not seriously shift the location of a swamp and the barrier beach that cuts it off from the main lake.

The writer made a list of some seven coal horizons, to which Cooper has added seven more. When we consider that the whole 14 occur within 400 feet, most of them too thin to work, and that one seam may vary 20 feet or so in elevation in a couple of hundred feet,

[1] Vol. III, Part 2, 42, 43, 96, 203; *Report* for 1907, 19; *Report* for 1905, 185, 188.

but little stress can be laid on any such series. The Verne bunch are, however, at a fossiliferous (Mercer) horizon often quite close together, showing as a 7- to 8-foot wall with partings (compare the Stockton coal) and it is curious that White gives 13 horizons in the West Virginia Upper Pottsville.

I have an idea that they give a drowned-river-valley effect to the southeast side of the basin, the longest axes of the coal running northwesterly in a very irregular way, but the general shore-line trending southwesterly from Huron County, something like the Carolina shore south of Hatteras turned around.

POSSIBLY PERMO-CARBONIFEROUS?

35. *Woodville sandstone.* 110 feet (Conemaugh).—Winchell separated off above the coal measures a sandstone 79 feet thick he called the Woodville. It was named from an exposure at Woodville near Jackson.

Now, at Maple Rapids, St. Johns, Ionia, and Gladwin,[1] we find a brown or reddish sandstone. This is not a normal color for a coal-measure sandstone. It may be that this reddening is an effect of weather, but I think not, and we may as well call it Woodville until we know the Woodville does not represent it. Ionia would be a much better name. The Woodville exposure is not red but buff. Still it is weathered, friable, and over 40 feet thick. From the way these red beds occur in some wells but not in others near by in the Saginaw Valley we may be pretty sure that they are unconformable to the series below. I suspect, therefore, that it is not Allegheny but at earliest Conemaugh, some land-formed deposit of the late Carboniferous (Pennsylvanian) or early Permian. No fossils are known. The red formations seem to be more abundant in the western part of the state but that part is heavily covered with drift, and the redness may be a purely secondary Mesozoic oxidation.

During the rest of the Paleozoic,[2] the Mesozoic and the Tertiary Michigan was, so far as known, out of water, though there is reason to believe that at the time of the Cretaceous the sea reached nearly or quite to it, and it was nearly worn down to base level. At some time everything from Niagara to Keweenawan around Lake Superior was

[1] Vol. III,,Part 2, 158, 159, 164, 166, 195, 196, 197.

[2] Schuchert, Pl. 84.

leveled off, and even the harder felsites and granites did not rise more than four or five hundred feet above the general level. As we find fragments of Upper Cretaceous not far off in Minnesota on the Mesabi Range we are inclined to put the culmination of this period of leveling at that time.[1]

On the other hand, deeply incised valleys and caves in limestones suggest a period of high level in the Tertiary between that time and the ice age. Some time someone may find in the prosecution of the limestone quarrying, around Fiborn or Alpena or Monroe in the caves upon which one comes, vestiges of Tertiary cave life. I do not know of any yet.

PLEISTOCENE AND RECENT DEPOSITS. 1,110–0 FEET

Michigan is so near the center of the latest glaciation and that was geologically so recent, the effects of ice blocking the St. Lawrence valley having lingered so far as one can judge until within a few thousand years, that it does not seem sensible to divide the Glacial and Pleistocene from the present. Mammoth and mastodon bones are found within a few inches of the surface and where forest clad, the topographic forms left by the ice are almost as sharp as when left, with much less alteration than 50 years of farming make. However, beds of peat 30 or 40 feet thick, of boglime, lacustrine, and alluvial clays 14 feet thick and perhaps more have accumulated and formations like the delta of the St. Clair flats, Tawas Point. So far as we can estimate none of these post-Glacial deposits need have taken over 10,000 years.

The greatest thickness of the Glacial-Pleistocene deposits we may estimate to be 1,110 feet near the north line of Osceola County, southeast of Cadillac. But the greatest thickness actually measured is in the deep wells near by on the Lake Michigan shore at Manistee and Ludington, where the rock surface is below sea-level, but they can hardly be separated systematically in a geological column. Both in the character of the pebbles, however, and in other ways, a transportation from the northwest as well as the northeast is plainly indicated, and at least one period between the two during which red lake clays were in some places laid down.[2]

[1] Schuchert, Pls. 94–95.

[2] *Report* for 1906, Russell on "Surface Geology," 43, 73; Rominger, I, Part III, 17.